ON MODELLING THE GENERATION AND PROPAGATION OF SEISMIC AND VOLCANIC INFRASOUND ON VENUS.

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Venus is Potentially Active: Global mapping from the Magellan mission [1] indicates that the surface of Venus appears relatively young. This youthfulness is evidenced by the current distribution of craters [2], indicating a potential volcanic resurfacing scenario [3]. Furthermore, the surface of Venus clearly features signatures of different types of geophysical events. For example, Tesserae exhibit tectonically-deformed terrain (ridges, fractures, and rifts) [4]. Volcanic edifices (coronae, domes, and shields) and lava flows are also prominent [5, 6]. Such clear and relatively recent markers of geologic activity suggest geophysical forces are still active today. Surface topography changes induced by these effects may be detected by radar sensors on the recently approved VERITAS and EnVision missions. However, recording seismic disturbances – critical to open a window onto our sister planet's interior and therefore to further pursue comparative planetary science – remains beyond the capabilities of these approved missions.

Acoustic Waves: Owing to mechanical coupling between planetary interiors and their atmospheres, geophysical events produce low-frequency atmospheric perturbations known as infrasound. Such infrasonic waves propagate upward and may be recorded by *in-situ* balloon-borne barometers or suitably-equipped orbital platforms. The recent selection of three missions to Venus has further intensified the scientific interest in the second planet, calling for a better understanding of the type of acoustic signals future *in-situ* missions might record. A catalogue of simulated infrasound signals on Venus is therefore essential to determine signal detectability and characterisation, and to contextualise measurements obtained from future missions.

Modelling Software: In order to model the solid-atmosphere system, we rely on the SPECFEM2D-DG software package [7, 8]. Resolving the coupled systems of elastodynamics equations for the sub-surface and Navier-Stokes equations for the atmosphere, this software has already proven to model terrestrial [9, 10] and Martian data sets [11] accurately. However, modelling the propagation of infrasound in Venusian conditions presents additional challenges that need to be addressed. Some of these challenges are listed below.

Geophysical Sources: First and foremost, a detailed description of the potential sources has yet to be determined. In this study, we focus on venusquakes and volcanic events. Among several fault types on Venus, wrinkle ridges (WRs) are globally distributed (65000 geographically correlated with the geoid), long (2–1400 km), low-amplitude compressive anticlines with orientations consistent over thousands of kilometres [12]. By limiting each WR to a reasonable faulting depth (10–30 km) and segmenting them [13, 14, 15], their moment release can be estimated using a scaling relationship [16]. Based on these arguments, the current distribution of WRs would have required at least 7.5×10^6 quakes with $M_\mathrm{w} \geq 4$ since the formation of the geoid [15]. This is a conservative estimate since activity may not be constant, segmentation patterns may vary, and many faults may be missed when mapped at the global scale. Volcanotectonic features are also globally distributed across the Venusian surface, including approximately 100 calderas ranging from 60 to 80 km in diameter and characterised by networks of concentric fractures along their periphery [6]. For such structures, we take an approach based on terrestrial analogues, which are known to generate seismic perturbations up to $M_\mathrm{w} \simeq 5$ [17, 18] as well as infrasound [19]. The collapse of the caldera blocks along the bounding ring faults [20] usually occurs in sequences of tens of repeating events which can persist for up to 160 days [17, 18], with a recurrence period as low as 50 years for Kīlauea [21]. Precise physical models of the seismoacoustic signals generated by caldera collapses have been developed using data from dense seismic arrays [22, 23, 19, 24], and could be used to model similar events on Venus.

Supercritical Lower Atmosphere: Thermodynamically, the lower atmosphere of Venus is in a supercritical state. Under those conditions, it is important to verify the domain of validity of the Navier-Stokes equations and to check that the input atmospheric models account for them. Moreover, atmospheric density near the surface of Venus is extremely high. In computational fluid dynamics, such fluids are intrinsically less stable and usually require adjusting the simulations' parameterisation. As a result however, the seismic-to-acoustic coupling is enhanced compared to terrestrial conditions, benefiting from the weaker impedance contrast.

Acoustic Attenuation: Carbon dioxide (CO_2), which contributes more than 96 % of Venus' atmosphere, possesses molecular vibrational relaxation modes. These modes induce especially severe attenuation on acoustic waves in frequency bands near the natural frequency of the vibrational modes, much stronger than classical thermo-viscous dissipation effects. A few vibrational attenuation models exist [25, 26], but are generally not validated against measurements [27]. Moreover, attenuation in supercritical fluids remains poorly documented. Extreme pressures and temperatures have generally counteracting effects on the molecular degrees of freedom, rendering the study of attenuation under those conditions highly non-trivial. Finally, waves travelling in the Venusian clouds suffer additional attenuation due to liquid vapour droplets, which induce diffusion effects and absorb part of the energy contained within the waves.

Methods, Results, and Outlook We present the current state of our modelling capabilities and limitations in the way of accurately simulating the propagation of seismic and volcanic infrasound on Venus. We focus on determining candidate source events, ensuring the selected approach is applicable to the Venus atmosphere, and investigating the effects of attenuation in thermodynamically challenging conditions. Our methods will rely on previous literature and analytical developments, and will be illustrated by sample simulations. This study is part of an effort aimed at investigating the feasibility of aerial seismology [28, 29, 30], and these elements will help establish a clear view of the steps forward in terms of simulation capabilities.

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